DOCUMENT RESUME

ED 442 630 SE 063 549

AUTHOR	Loughran, John; Gunstone, Richard; Berry, Amanda; Milroy, Philippa; Mulhall, Pam
TITLE	Science Cases in Action: Developing an Understanding of Science Teachers' Pedagogical Content Knowledge.
SPONS AGENCY	Australian Research Council.
PUB DATE	2000-05-00
NOTE	36p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (73rd, New Orleans, LA, April 28-May 1, 2000).
PUB TYPE	Reports - Research (143) -- Speeches/Meeting Papers (150)
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	Elementary Secondary Education; Foreign Countries; Higher Education; *Knowledge Base for Teaching; *Pedagogical Content Knowledge; *Science Teachers; Teacher Education; *Teacher Effectiveness; *Teaching Skills
IDENTIFIERS	Australia

ABSTRACT

This paper describes the rationale for and progress in a substantial research project that aims to develop an understanding of science teachers' pedagogical content knowledge. The background to and purposes for the project are explained. Related projects that study pedagogical content knowledge (PCK) are also described. Approaches to identifying PCK are outlined, and an example is used to describe a new approach. (Contains 18 references.) (WRM)

Reproductions supplied by EDRS are the best that can be made
from the original document.

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION
CENTER (ERIC)
This document has been reproduced as received from the person or organization originating it.
Minor changes have been made to improve reproduction quality.
Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

ED 442 630

Science Cases in Action: Developing an understanding of science teachers' pedagogical content knowledge

John Loughran, Richard Gunstone, Amanda Berry, Philippa Milroy and Pam Mulhall
Faculty of Education, Monash University
Australia

A paper presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, April, 2000

The research reported in this paper was supported by an Australian Research Council Large Grant (Loughran and Gunstone, 1999).

BEST COPY AVAILABLE

Science Cases in Action: Developing an understanding of science teachers' pedagogical content knowledge[i]

John Loughran, Richard Gunstone, Amanda Berry, Philippa Milroy and Pam Mulhall
Faculty of Education, Monash University
Australia

Introduction

The essential focus of this paper is to describe the rationale for and progress in a substantial research project whose purpose is well summarised by the title of the paper. We begin by elaborating a little of the background to and purposes for the project. We then consider relevant aspects of the ways in which pedagogical content knowledge (PCK) has been used by other researchers with broadly similar intents, and describe our current position with respect to aspects of PCK of importance to those who seek to identify and understand it. Then we outline the approaches we have used in our attempts to identify PCK, and conclude with a description of a new approach, through the use of an example.

Background to the project

Teaching requires specialist pedagogical knowledge that is developed and refined by practitioners over time and through extensive experience. This knowledge comprises an understanding of such elements as (for example) content, teaching strategies, learning styles and theories, and context. This specialist knowledge is obviously important in teaching, but becomes even more important when the integration of this knowledge, termed pedagogical content knowledge (Shulman, 1986), is recognized and understood as the complex amalgam of all of these elements contained in the practice of expert teachers. This PCK is then one part of the professional knowledge of those teachers who have mastered the individual elements (described above) of teaching knowledge and combined them in their teaching so that they teach particular content in ways that will best engender students' learning science for understanding.

Science teachers' professional knowledge about teaching is often undervalued and misunderstood (both within the profession and the community generally). Often this is because it is too easy to dismiss the knowledge as not explicit. However, this does not mean that specific and valuable knowledge about how to teach science does not exist, rather it suggests that the recognition of this knowledge and our ability to articulate and document it is lacking.

Understanding how science teachers organize and conceptualize their teaching in order to enhance student understanding of the concepts being taught is a field of research which probes the very essence of teaching itself and may well be described in terms of the search for the expert pedagogue (Berliner, 1988). "What does a science teacher consider when determining how to teach a particular concept?"

Loughran, Gunstone, Berry, Milroy and Mulhall. A paper presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, April, 2000.

"Why does the science teacher use teaching strategies for some concepts and not others?" "What reasoning underpins the science teacher's practice?" "How does a science teacher's understanding of learning influence their pedagogical reasoning and thinking?" These questions are at the heart of understanding the specialist knowledge of science teaching and are important in determining how knowledge about science teaching is developed and refined. We have been attempting to capture this knowledge through an *adaptation* of the use of 'cases' (Shulman, 1992; Mitchell and Mitchell, 1997).

In this project, begun in February 1999, we have been attempting to address many of the questions germane to the codification of pedagogical content knowledge of science teachers, and hence to help to demonstrate the value and importance of such knowledge. This paper illustrates briefly how PCK is described and understood through the literature, and then how that understanding influences our developing view(s) of PCK. In so doing, we outline some of the methodological tensions and dilemmas we have faced in attempting to 'find' PCK. We then elaborate, with examples, the approach we are developing to document and share this knowledge with others.

Pedagogical Content Knowledge in Science Teaching

Rarely has a new construct in education had such rapid and widespread acceptance as Shulman's PCK. First written about in 1986 (Shulman, 1986), with a more widely cited elaboration a year later (Shulman, 1987), it has quickly become commonly used by researchers, policy advocates, and many others (eg Gess-Newsome, 1999, p.3). While this acceptance might in part be linked with Shulman's passionate advocacy of the depth of expertise evident in good teachers/teaching (certainly an issue of importance for the authors of this paper), it is a clear indication of a belief among many educators that Shulman has captured something of real significance in the construct. For 15 years it has been a seductive construct. This belief in the significance of PCK has been influential in considerations of teaching across the curriculum. Our concern here is of course for PCK in the context of science education.

Influential on and seductive for researchers PCK may have been; it has also been interpreted in varying ways. This important, although obvious, point is well illustrated by the experience of one of the authors of this paper in acting as a discussant for a set of papers concerned with elaborating PCK presented at a previous NARST conference. The four papers each took a different meaning for PCK. These meanings, as paraphrased by the discussant, and the nature of the individual(s) whose PCK was being studied, were:

- how prospective teachers learn to transform their science subject matter into comprehensible units of meaning for a diverse group of students (students in a teacher preparation program for High School chemistry)
- the ways in which the subject matter of the curriculum may be represented and structured in order to pave the way for understanding (teachers learning about a new elementary curriculum)

- teachers' knowledge of representations and instructional strategies in relation to knowledge of student learning, both with respect to a specified content area (teachers preparing for a new High School curriculum)
- content knowledge that has been specially crafted by the teacher to suit the schooling and personal needs of his or her students…evolves…flexible (one "deified" teacher)

Each of these four views is certainly consistent with descriptions of PCK advanced by Shulman such as "the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the ways of representing and formulating the subject that makes it comprehensible for others" (1986, p.9) and "[p]edagogical content knowledge is the category [of teacher knowledge] most likely to distinguish the understanding of the content specialist from that of the pedagogue" (1987, p.8). Even so, the four are clearly not specifically the same – for example, one talks of a process ("how prospective teachers learn to transform…"), another particularly of instructional strategies; one clearly implies that PCK is collectively seen across a group of teachers ("teachers'…"), another is concerned only with an individual teacher, while the remaining two could be either individual or group.

At one level such inconsistency is not surprising – as already noted this has been a construct of great influence on thinking for 15 years and researchers have taken many directions in their attempts to understand and represent PCK. Nor is it at all new to point to this inconsistency in detail of researchers' understandings of PCK (eg Gess-Newsome & Lederman, 1999; Veal & MaKinster, n.d). The significance of the inconsistency in detail for us in this project is the obvious point – as we have sought to try to make explicit and represent the PCK of science teachers, we have been working with an intertwined complexity of the two central issues of our research: (i) explorations of methods by which we might reveal and then represent PCK, and (ii) what it is that *we* specifically mean when we talk of PCK.

Our thinking has been influenced by returning to Shulman's (1987) seven categories of teacher knowledge, in particular what we choose to term the "boundary" issue that is well represented by the categories. By this we are pointing to the fact that when one considers some movement in the "boundaries" between some of Shulman's categories, the other boundaries between other categories also mostly move. This is certainly true of our current conceptualisations of PCK, as discussed below. We have also been conscious of the need to at least consider some of the early critiques of Shulman's initial conception of PCK, in particular the arguments of Grimmett and MacKinnon (1992) that PCK is different *in kind* from the other categories of Shulman – (while the other categories of knowledge can be taught and then applied), PCK is formed over time through reflection, thus having some form of linkages with what Shulman called "the wisdom of practice".

Before turning to an outline of how we are currently thinking about PCK (at least at the time of writing this paper), the four examples of different detailed conceptions of PCK given above are revisited. This is done to elaborate two issues already alluded to that are of particular significance to our thinking about

PCK – (1) collective versus individual views of PCK; (2) complexities arising from what we term the "boundary" problem.

We contend that the issue of whether PCK is collectively seen across a group of teachers or is concerned only with an individual teacher is both insufficiently considered in some conceptualisations of PCK and sometimes implicitly assumed to be "group" in writing about PCK. Even in some studies of PCK where the initial data on which the study rests is derived from individuals, the conclusions to the study are presented in "group" terms even though there is no explicit indication of the thinking of the researcher(s) about this shift. For us the issue has centrality both for our conception of PCK *per se* and for one of our central research concerns (understanding/elaborating PCK to enable it to be accessed by other science teachers). One way to consider the issue is through the notion already described of the expert pedagogue (Berliner, 1988), and the questions already given to illustrate this: "What does a science teacher consider when determining how to teach a particular concept?" "Why does the science teacher use teaching strategies for some concepts and not others?" "What reasoning underpins the science teacher's practice?" "How does a science teacher's understanding of learning influence their pedagogical reasoning and thinking?" We doubt that anyone would seriously subscribe to the idea that the search for the expert pedagogue involves a search for the single, supreme paragon of excellence. However, studies of expertise in science (or other) teaching rightly do very often focus, at the very least in data collection, on individual teachers. It may suit the purposes of the research to then somehow combine individual examples, or elaborate to place in a broader context the work of one expert teacher. This is the essence of our view. We do not pretend that the "group" versus "individual" issue is a simple one. Tensions arising from this are frequently evident in our own attempts to understand and document PCK. But the essence of our current thinking is to recognise the need (even necessity?) to initially work with individual teachers, but to then see it as appropriate to not necessarily preserve in total detail any individual teacher's thinking/approach in our approaches to creating a valid representation of PCK to place before others.

Two other aspects of this "group" versus "individual" issue have influenced our thinking. One is the existence of expertise that has a group element (most obviously in contexts of genuine teacher collaboration such as is represented by groups such as the Project for Enhancing Effective Learning; eg Baird & Northfield, 1992). The other is the more fundamental, and much more problematic issue, of the difficulty of representing the reflection that is central to individual PCK. It is often much easier to validly represent this if it is seen as acceptable to go further than just representing the thinking of a single individual.

Two of the four examples of difference in detail of conception of PCK given above illustrate our most difficult "boundary" problem. One of the above examples sees PCK as a form of teachers' knowledge as viewed through a lens of knowledge of student learning ("teachers' knowledge of representations and instructional strategies in relation to knowledge of student learning"), another sees PCK as " pav[ing] the

way for [student] understanding" through representing and structuring the "subject matter of the curriculum". These two views see quite different boundaries between PCK and more general knowledge of learning (another Shulman category). This boundary has been the one that is most problematic for us, and our consideration below of our current views of PCK reflects some of our dilemmas here.

We turn now to an outline of how we are currently thinking about PCK. We do *not* do this for any reason of suggesting that our current thinking has particular merit in its own right, but in order to provide necessary context for the subsequent description of an approach to making explicit and presenting PCK.

Our developing views of science teachers' Pedagogical Content Knowledge

Our developing views of science teachers' PCK have been refined through our attempts to uncover and document that which we initially conceived to be a recognisable and articulable body of knowledge that experienced science teachers possessed.

It has become increasingly clear to us through our research that although PCK may well exist, it is an even more complex process to recognise or articulate PCK than we originally expected. There are numerous reasons for this realisation, some of which include:

- PCK is not simply associated with the development and delivery of a particular lesson. Good teaching activities may contribute to PCK but are not usually expansive examples of PCK on their own.
- PCK is a complex notion often only recognisable over an extended period of time – perhaps the teaching of a unit of work eg. the particle model.
- Experienced science teachers do not commonly talk about PCK when they are discussing their teaching. They may sometimes focus on issues of learning or issues of teaching but more generally focus on teaching procedures, activities and strategies; hence PCK is not a "part" of their professional language or a construct with which they are necessarily familiar.
- Although experienced science teachers may have a wealth of knowledge about both the content and pedagogy appropriate to science teaching and learning, much of this knowledge is tacit and therefore difficult for individual teachers to recognise and express.
- PCK develops through coming to understand concepts/content differently as a result of attempting to teach those concepts/content and recognising the inherent incongruities in the knowledge and developing an understanding of it in practice. (The next point is then partly as a result of this one).
- It is difficult for teachers to reconstruct the development and changes in their teaching over time. Therefore, knowing how they once understood a concept/content area and knowing how and why that understanding has changed is exceptionally difficult.

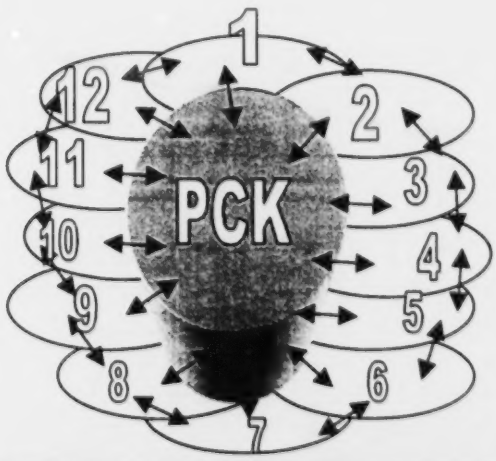
- "Seeing" PCK involves using a complex array of "instruments", some of which involve interviewing, classroom observation, curriculum discussions, collaboration with other teachers, testing and challenging one's boundaries between beliefs and practice.

Considering the above (which is not intended as an exhaustive list but as an indication of some of the influencing factors), we contend that to "see" PCK is not to see PCK at all but rather to see a mixture of interacting elements which, when combined, help to give insights into PCK. However, as the mixture of elements invariably vary, so PCK itself is variable in that the different mixtures of elements influence the richness of the PCK and changes in any of the elements inevitably influences the nature of the PCK that is being portrayed.

Some of these elements include (for the sake of the Figure 1 below, numbers are used to help make representation easier):

1. Views of learning
2. Views of teaching
3. Understanding of content – how that understanding has developed and changed
4. Knowledge and practice of "Children's Science/alternative conceptions"
5. Time – teaching time/length of unit/unit of work
6. Context – school, classroom, year level
7. Understanding of students
8. Views of scientific knowledge
9. Pedagogical practice
10. Decision making
11. Reflection
12. Explicit vs. tacit elements of knowledge of practice/beliefs/ideas

Figure 1: Interaction of some of the elements of PCK



With these elements in mind, the overlap of each clearly influences what the PCK actually looks like and, although this is difficult to illustrate through a diagram, the notion is that *all* elements influence one another in such a way as that the overlap with any one is not limited to that alone and that the PCK is the amalgam of all in the mixture available and presented (or able to be presented at the time).

If it is possible to imagine a complex array of elements such as those listed above as contributing to what PCK might actually encompass then one other important factor is the 'destination'. By destination we mean where a teacher envisages where and how they want the content/concepts under consideration to develop through the teaching and for the students' learning. It is this destination that influences the rich tapestry of PCK that is called upon by experienced science teachers to teach about the science with which they are involved.

Method

Throughout this study we have slowly been developing ways of attempting to recognise and capture PCK. Whilst being an exceptionally seductive academic construct, PCK has proved to be quite elusive. Part of the difficulty associated with 'finding' PCK is embedded in the 'frame' (Schön, 1983; 1987) that researchers bring to the 'problem' and our framing has certainly been challenged (and has changed) throughout this project.

Our framing

As a research team we have had many discussions about the nature of PCK and how we might recognise it, assuming we found it. Initially we were concerned that our personal views of teaching and learning, which are informed by constructivist theory, might influence in a negative way our ability to recognise PCK in non-constructivist teaching (should it exist). We therefore attempted to be as open minded as possible about what PCK might 'look' like. Our working definition of a science teacher's PCK was that it had to do with a way of knowing about particular science content (by which we mean propositional knowledge) which enables a teacher to teach it in a manner which best engenders learning for understanding in his or her students. It was our view that all teachers would have some level of PCK but that it would be most well developed in very experienced teachers. In the course of our research we have refined our ideas somewhat. In the first instance, our notion of PCK was such that we envisaged finding expert science teachers who more than likely had well-developed PCK, but were perhaps unable to personally articulate it. Hence, we thought we might be able to see PCK through such things as content specific teaching procedures - eg. role plays, laboratory work designed and implemented with particular purposes in mind (Hart et al, in press), demonstrations etc., through discussions with teachers about their teaching, through classroom observation, and other 'traditional' approaches to seeing 'knowledge through the practice' of experienced science teachers. However, our hopes were not realised as PCK was neither easy to see nor to articulate. On the other hand, we did 'see' elements of PCK and we describe instances of this later.

Our current view of PCK is that it is not useful to view it solely as something an individual teacher has but rather as something that resides in the body of science teachers as a whole. Different but complementary aspects of PCK can be revealed through exploration with individual teachers and with groups of teachers. These involve different methodologies, which we have termed 'individual' and 'collective'. The individual and collective methodologies operate on two levels, in terms of both data collection procedures and the data itself. We shall explain this differentiation through an elaboration of Figure 2:

Figure 2: Changes in method over time in response to our changing understanding of how to capture and represent PCK

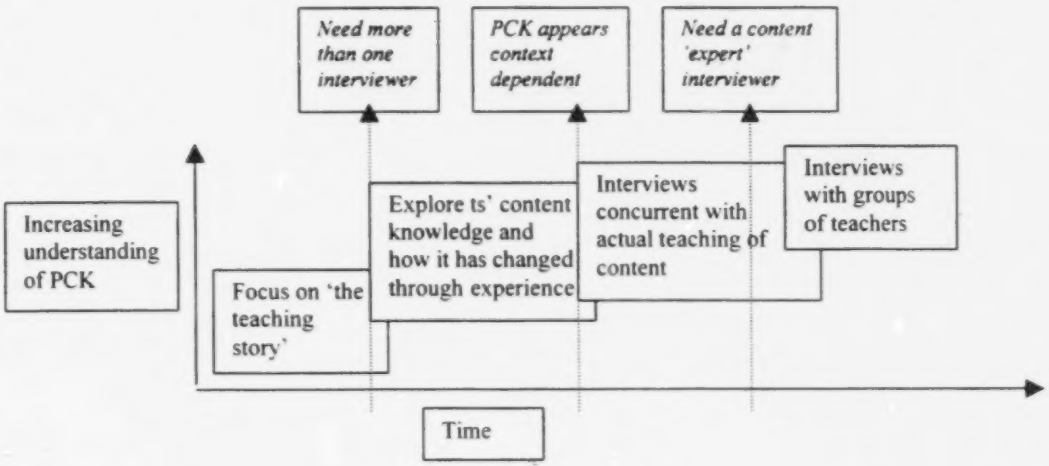

Need more than one interviewer
PCK appears context dependent
Need a content 'expert' interviewer
Increasing understanding of PCK
Focus on 'the teaching story'
Explore ts' content knowledge and how it has changed through experience
Interviews concurrent with actual teaching of content
Interviews with groups of teachers
Time

Figure 2 is designed to illustrate the changes in method and the learning outcomes derived from these changes. Our understanding of our approach to data collection led us to better ways of coming to 'see and hear' about PCK.

Individual Methodologies

Our first attempt at 'capturing' PCK was through interviewing individual experienced science teachers. and attempting to 'unpack' their approach to teaching a particular content area in science (eg. electricity, states of matter) in relation to our understanding of PCK. Although the science teachers we interviewed certainly had a very good working knowledge of their teaching, there were noticeable difficulties associated with the articulation of their knowledge about their practice. This was in part due to a lack of a common vocabulary about teaching and learning, and also because much of their knowledge is 'knowledge in action' – knowledge which they are rarely if ever asked to make explicit; teachers rarely talk about the details of the content that they teach.

The teachers we interviewed

Our original intention was to interview as representative a selection of teachers as possible[1], even though we thought that PCK would most likely be found in experienced teachers. In fact of the eleven science teachers we interviewed, all but one had fifteen or more years teaching experience. Some had taught just general science while others had also taught one or more of the specialist science subjects (physics, chemistry, biology). We learned very early in the project that because a teacher was 'experienced' it did not necessarily follow that he or she had also seriously thought about their approach to teaching, reputations for excellence not withstanding. Such teachers were able to tell us little beyond the broad details of a lesson plan (we give an example of what we mean by this later in the paper). As we ourselves were still struggling to understand what PCK might 'look' like, and how to document it, we became more selective so that most of those interviewed were chosen because of their reputations as 'good' and reflective teachers. We believed that it was more likely that we would be able to 'uncover' PCK in such teachers.

How we explained our project to the teachers

An immediate problem was how to convey to these teachers what our purposes were. Pedagogical content knowledge is not a term that most teachers are familiar with! More importantly the notions described by the term PCK are not part of teachers' thinking (see below). As former science teachers ourselves we felt that the term 'teacher know-how' gave some sense of what we wanted to explore. In the early invitations to participate in the project, we said we were trying to get at 'the heart of understanding how science is taught most effectively', as the documenting of this teacher know-how would be a valuable resource for the profession. Later, because of our difficulties in uncovering PCK, we also provided - in advance - a running sheet of interview questions so that the teachers concerned had some time to think about their teaching in terms of the issues we hoped to explore. For these teachers the interviews were more like 'conversations' as they discussed with us their difficulties in responding to our questions. These difficulties occurred as a result of our need to make the tacit nature of their practice explicit for us, which is not a normal expectation of being a teacher; it is not a cultural norm of the profession.

What we asked the teachers

As noted earlier, our initial conception of PCK was that it had to do with a teacher's knowledge of content that enables them to teach it to a particular group of students in a way that best engenders learning for understanding. Prior to and following each teacher interview, the research team had many meetings, both formal and informal, in which we grappled with:

[1] We planned to find these teachers by 'advertising' our project at a number of conferences for science teachers. However, this resulted in only one volunteer so we then approached teachers we knew, including some colleagues who were still involved in teaching science or had taught it recently.

- the notion of PCK and the question of its existence. Embedded in this is the question of whether PCK is just an academic construct or something that teachers themselves (might) recognise that they possess.
- how to find it. We constantly discussed the usefulness of various kinds of interview approaches and kept a running sheet of questions that might be useful for probing an interviewee's responses.
- how to represent it. As we hoped to use an adapted form of case writing, we sought, at least initially, responses which might be useful for this, eg snapshots of classroom behaviour and instances during a class of specific teacher decisions.

As our thinking about these three questions changed in response to our discussions, the interviews we had conducted and our reading about PCK, so too did our approach to the teacher interviews. Basically we moved from asking very general questions which allowed a range of responses to those which were much more focussed.

At the outset our interviews centred on the initial question, 'Tell us about something you teach in a particular way for a particular reason, and why'. We were interested in seeing if teachers would respond in a way that indicated their framing of their teaching had some links to our notions of PCK. However, as the question did not necessarily lead to teachers talking about teaching content we changed it to 'Tell us about particular content you teach in a particular way for a particular reason, and why.'

In exploring the reasons for a teacher's response we sought to find out what knowledge of teaching, learning and content influenced their teaching of specific content. In particular, for each content area that the teacher chose to talk about, we tried to 'unpack'

a) what content the teacher intended that the students learn from his or her teaching and why
b) what they actually learned and why
c) the teacher's own understanding of the content. (This was important because it is a determinant of a) and, as we discuss below, soon assumed even greater significance in our thinking as a marker of PCK.)

It was actually very hard to get teachers to speak separately about these three things for they often spoke as if a) and b) and/or a) and c) were one. They also spoke in generalities eg "I want them to understand inertia" as opposed to "I want them to understand that inertia is …". It was difficult for us to push them to be more specific in ways that did not threaten their status as content experts.

As our picture of PCK evolved we came to the view that it might be revealed through exploring how a teacher's understanding of specific content had changed since they started teaching. We considered that a consequence of teaching particular content in a particular way would be a change in the teacher's understanding of that content – for example, the teacher's knowledge of a particular concept would now include understanding of how difficult it is for students to understand the concept, what helps overcome

these difficulties etc. We therefore tried framing the interview differently: 'Tell us about something that you teach where your understanding of the content has changed since you first taught it.' Then we tried to explore how their understanding had changed and developed; the factors that had influenced this development; and, how teaching the content had altered their understanding of the concepts. We hoped this line of questioning would help to recreate, in the teacher's mind, the way they had come to know the content and hence make the link between that knowledge and their teaching approach more explicit. This was more helpful but there was still a tendency for the interviewee to move across a range of content areas and hence shift focus and not concentrate on anyone particular field, thus offering summative views of classroom practice rather than 'rich' pictures of content related pedagogy.

It became clear to us that settling on **one** content area from a short list of specified topics (eg. electricity, states of matter etc.) prior to the interview was important in order to help the interviewee conceptualise what it was they were being asked to reflect upon. It was also obviously important that the content area was one that the teacher felt some degree of expertise in, and was comfortable discussing.

Despite a number of individual interviews, we learnt more about what did not work rather than what did work. For example, after one round of individual interviews, it emerged that when we interviewed a teacher and had two researchers present, one of whom was a content expert, that the interview markedly improved. The presence of a researcher who was not an 'expert' in the particular content area being discussed was also helpful as many of the questions for clarification helped to expose the assumptions associated with the teaching of that particular content. However, after a number of interviews using more than one interviewer, we continued to feel frustrated that the elusive PCK was still not standing out as something able to be captured and displayed for others.

Our expectations of these interviews

Throughout this process of individual interviews, our notion of PCK was that it was an 'isolatable' item, and hence a recognisable data source. In working with expert science teachers, we were partly searching for the peaks and troughs in their pedagogy that acted as 'markers' or 'triggers' (Kadar, 1998) in their practice. Through helping the teachers to articulate these points, we felt it would be possible to map out their PCK in relation to the trigger that caused them to teach a concept in a way that hopefully enhanced student understanding. In one sense, we were attempting to find identifiable instances where a concrete pedagogic action was employed for a particular reason in response to, for example, a learning difficulty, or situation, need, or known point of confusion in the content being taught. In reality, we were perhaps searching for individual instances of PCK in action, or individual lessons where PCK was being obviously employed. Although we had insights into teachers' use of teaching procedures, we did not feel as though we were particularly uncovering PCK.

Classroom Observations

The next step in the refining of our methodology was to mix interviewing with observations of classroom teaching. In this case, particular classroom episodes (White, 1988) that were noted during a lesson were used by the interviewer(s) to help in a process of stimulated recall, so that the teacher's/students' actions could be used as a way of revisiting the situation and therefore exploring the nature of the teaching and learning. Again, although we developed ways of understanding better what was happening in the classroom and the factors which influenced the teaching and learning that we were observing we did not feel as though we were actually tapping into the teachers' PCK.

Our emerging view of PCK and how to represent it

During this process of working with individual science teachers we did see what we considered to be elements of PCK in action. It was the development of these small insights that led to the view of PCK outlined in the first section of this paper (Figure 1) whereby we could see the overlap of a number of elements influencing in different ways the nature of the pedagogy of the individuals we were working with. Thus the understanding began to emerge that PCK was not 'an individual item' but a mixture of items that were not necessarily 'fixed' but varied with the context of the teaching and learning situation.

There are many examples we could cite to illustrate this point but one that we have found particularly powerful is that offered by Rhonda. We interviewed Rhonda about her teaching of 'States of Matter' and observed her in action as she taught this topic. She made it clear that her teaching was purposeful and that what she taught was influenced by the age of the students. She also noted how important it was for her as a teacher to recognise the contradictions in the nature of the knowledge portrayed to students by different sources. In the case of the particle model of matter that she was currently teaching she noted how textbooks could contradict a particulate view through their schematic representations. As a Chemistry major she noted with some disdain that many textbooks illustrated the particulate view of a liquid but 'contained' it by a continuous line (see diagram 1 in the detailed discussion of the PaP-eR; Seeing Things Differently, p. 24 - 27). This recognition of one type of 'inherent contradiction' within a content area and its implications for student learning illustrated, we believed, elements of this teacher's PCK. Referring to Figure 1, it illustrated the interaction of many, but not, all the elements shown. At another time Rhonda spoke about her belief that only a very small fraction of her year 7 class would attain a particulate model as a result of her teaching, with the rest retaining a continuous model. This again demonstrated elements of her PCK, but a different mix from before. These two instances represent portions of her PCK but do not convey the whole picture[2].

[2] A possible analogy is a piece of jazz music. To listen to it being played at a particular instant is to know what it sounds like at that instant but not the next because the sound changes as the players interpret the piece. In addition the sound at an instant results from the mixing of the notes from the various instruments and these change in intensity and pitch over time. And the same piece played by the same musician at another time will very likely have deliberately changed sounds.

We came to see that, rather than being fixed, the nature of 'seeable' aspects of PCK varied with the situation even if the content was the same (as per Figure 1). The implications of this for our original intention of portraying PCK through case writing is discussed later.

Collective Methodologies

During our interview/observation phase of this project, we spent many hours in research team meetings discussing what was emerging, how it helped to refine our understanding and what we needed to do next to move forward. At one such meeting, we planned a workshop session at the forthcoming Science Teachers' Association of Victoria Annual Conference to explore another methodology. We anticipated that it would enable us to access more expert science teachers' understandings of their science teaching.

We developed a workshop activity that was designed to get teachers to think about, and share with others, their knowledge about how to teach particular science content well which they had developed through their practice. The activity was based around the table shown in Table 1.

Table 1: Table used to access teachers' knowledge about how to teach particular content.

TOPIC:

YEAR LEVEL:

	IMPORTANT SCIENCE IDEAS/CONCEPTS			
What you intend the students to learn about this idea.				
Why it is important for students to know this.				
What else you know about this idea (that you don't intend students to know yet).				
Difficulties/ limitations connected with teaching this idea.				
Knowledge about students' thinking that influences your teaching of this idea.				
Other factors that influence your teaching of this idea.				
Teaching procedures (and particular reasons for using these to engage with this idea).				
Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses)				

Working in small groups, the task for the teachers was to consider what they perceived as being the main ideas or concepts in teaching a particular content area and how they would go about helping their students to understand those ideas. The table comprised a list (shown down the left-hand side of Table 1) of

aspects[3] to consider in order to teach each important idea or concept. Having discussed and agreed upon the main ideas for the content under consideration, the teachers then considered these in terms of the aspects listed and completed the table as appropriate. We recognised the limitations of the table and regarded the borders between the various categories as flexible (not least because it was not possible to study each idea in isolation from the others). We also encouraged teachers to write outside the table and draw appropriate links to the table.

From our viewpoint as researchers of PCK the workshop, which was received very positively by the participants, had several significant outcomes:

1. An affirmation by the teachers that what we considered to be important aspects to consider when teaching a particular idea (as shown in the left hand side of Table 1) were also valued by them. This was achieved prior to the activity involving the table through an exercise in which they were asked to generate their own list of things to consider when thinking about teaching particular content well. There was strong congruency between their list and ours. As our list had been developed as a result of our experiences interviewing single teachers about their teaching of content, we felt this was some justification for the framework within which we were working. In other words it validated the things we considered to be important in any representation of PCK.
2. The teachers valued the activity, both the process and the product, which was important for us because this links strongly with one of the project's aims which is to document teachers' pedagogical content knowledge as a resource for the profession. They also suggested that school science faculties would find the exercise useful. We felt that they derived satisfaction from the framework for viewing their teaching and the opportunity to discuss this with their peers. As we have noted before, teachers rarely have the opportunity to reflect on what they do. Hence much of their knowledge is about what 'works' but not why, and this opportunity to work together and to discuss practice through another frame was valued.
3. We referred earlier to the difficulty of getting teachers to talk about their knowledge of practice, particularly in terms of content. The workshop activity was successful in getting them to talk about teaching content partly because of its collaborative nature which was less threatening than asking them to talk about their own content knowledge per se (as we had done in the individual teacher interviews).
4. An important outcome of this success was the realisation that the interaction of some of the elements of PCK emerging through collective discussions were illuminated as experienced teachers began to respond to one another's ideas and approaches to teaching particular content. This reinforced our emerging view that PCK was a dynamic collection of elements that influenced a teacher's approach to teaching specific content. In addition we concluded that the notion of a collective PCK across

[3] This list summarised what we considered to be important facets of how to teach particular content well that were missing to a greater or lesser extent in the interviews we had conducted with individual science teachers.

professionals was a valuable perspective for representing knowledge about how to teach particular content for understanding (ie. that through focussed discussion on teaching and learning within one content field, science teachers' collective wisdom illustrated the variation in PCK for that content and offered insights into some of the factors that influenced how the various elements were recognised and played out in practice).

Through this development in our understanding we came to view PCK somewhat differently to that which we had initially started searching for and began to recognise why it was that there was such a paucity of concrete examples of PCK in the literature.

Representing PCK

Our project had two main aims: (1) to 'uncover' PCK; and, (2) to create representations that portrayed it to other teachers (hopefully in ways that might also be useful in helping them to recognise and develop their own PCK of particular content). Through our early attempts at documenting PCK, we came to see that the 'case approach', although excellent for highlighting and illustrating teaching dilemmas, was not as appropriate for portraying PCK as we had initially envisaged. There is a great divergence of elements that we believe can be 'indicators' of well-developed PCK. Hence the examples of 'PCK in action' that we encountered were not always 'cases' of practice, but rather various insights or 'windows' into particular instances, ideas, shaping factors and so on, that interact with this academic construct that we have been trying to render tangible.

Initial attempts at portraying PCK

In an attempt to illustrate how our understanding about the portrayal of PCK has changed over time, we offer the following vignette - reconstructed from an interview with a teacher of year 9 general science conducted early in the project. This interview - and the vignette produced - with others contributed to the evolution of our early data gathering approach described above (method section). We include this vignette only to illustrate some of the inadequacies we encountered in initially attempting to portray PCK. It is a 'classroom window' but not a case, as it is presented without a dilemma. As such it describes the 'goings-on' in this teacher's classroom, but lacks any hint of the 'problematic nature' of either the content or context, or for that matter any sense of the decisions being made. The vignette is really the teacher's response to the question, "How do you teach about states of matter to year 9 students?" It does not start to probe the deeper question of, "What is it that you take into account when deciding how to teach it to this group of students?" (a form of inquiry that was really only implicit in our initial methodology). Through a dissection of the vignette 'States of Matter' and exploring what we found to be lacking, we can now illustrate what we believe is needed in a representation of pedagogical content knowledge.. The callout boxes accompanying this vignette flag some specific questions that a reader might ponder when

considering how this teacher went about her teaching of states of matter with this particular class and illustrate some of the complexities of the issues associated with attempting to portray teachers' PCK.

The callout boxes can be seen as marking the 'gaps' that this account needs to illuminate in order to better 'hear' the teacher's thinking, prior to, during and even after the class, as well as more of the likely student responses. In addition to this, the account must also carry 'what it is about the content' that the teacher knows and brings to bear during the teaching so that it impacts on students' learning in the ways intended/anticipated. The callout boxes help to question aspects of the subject matter, decision-making, students' thinking and the underlying intentions related to making sense of the subject matter. Similarly, it is important that we 'hear' how students comment about and react to the details of the subject matter and the way it is covered.

States of Matter

The science lab. benches have an array of 'things' out on display inviting the students to wonder what they will be doing in the lesson. There are plastic, foam, wood, a well sealed bottle of mercury, an ampoule of bromine, other coloured liquids, all sorts of things. Gases are represented by things like a light bulb, or a covered flask of air.

This could be a link that may be very challenging for some students to make – did the teacher see it that way?

The students start sorting the things into groups. Not surprisingly for Year 9 students, most sort the 'things' into solids, liquids and gases. Then in small groups they begin to discuss their classification systems and started to write up what they have done and why. They spend time thinking about what they have seen or done and then begin to explain why they have ordered 'things' the way they have.

This account does not indicate why the teacher included this first activity. If the students were already familiar with the categories solid, liquid and gas (as the vignette indicates later) then they would probably use these terms as category labels. So did the teacher explicitly ask them to explain *how* they decide which label to apply? Were there any items difficult to categorise?

"These things slosh around in the container."

"You have to bash these to change their shape!"

Next, the students mill around the teacher who has an old speaker. She pours ball bearings into the speaker – the ball bearings sit together creating a nice cone shape. She then powers up the speaker. It starts on low. There is a *gentle rumbling and the ball bearings move a little but maintain their* positions.

Do the students or the teacher comment on the way the ball bearings jiggle? Does the teacher make explicit reference to how difficult this is to believe – that the particles are not completely still in a solid?

This is a reference to previous work on solids, liquids and gases. But, we need to know about that work. This is then further illustration of complex ideas previously introduced to the students. In relation to particle theory, is there an *assumption that students* have accepted the notion that everything is made up of tiny bits rather than continuous matter? Are the students working through how particle theory might be useful in explaining solids, liquids and gases or is the teaching simply presenting it without acknowledging the difficulties of alternative conceptions or the complexity of the concepts.

After some discussion about the demonstration the students are reminded of the previous work they have completed on solids, liquids and gases. Eventually a student recognises the intended analogy and offers a response to the teacher's question of "What does this look like?" by saying, "It's like a solid isn't it?"

The teacher offers an affirming grin and encourages the students to watch again. She turns the speaker up a little further this time and the ball bearings start to move around. One student chimes in quickly with, "A liquid Miss, it's starting to be a liquid". The teacher says nothing but adds a few coloured marbles to the 'brew'. The movement of these coloured marbles is easy to follow and the students comment on it as they change positions and move about amongst the ball bearings. It seems apparent that movement of the 'ball bearing liquid' has been noted – the particles are moving around in a way that was not the case in the 'ball bearing solid'.

What do students think about using sound through the speaker to create this experience? Do they link it to heat increasing the kinetic energy of the particles in a substance? Are there any problems in modelling it this way?

Suddenly there is a roar and students in the next classroom must surely be wondering what is happening in the science lab. The ball bearings start bouncing up and down and sometimes go flying out of the cone. There is no hesitation as students call out, "It's a gas Miss." The teacher smiles.

Does the teacher draw the attention of the students to the transition between the phases and what happens as a result of this? How does she help students 'see' the different states as positions along a continuum? Is student confusion (which can be both helpful and healthy) evident through questions such as, "can a particle of water be a liquid?"

The teacher then uses a 'standard' role-play to give the students a 'feel' for the changes in state. She pushes the benches around a dozen volunteers, penning them into the space between. The students are told to grab each other and hold on tight. She asks others to look closely at what is happening, pointing out that "Even though they're 'penned' in and staying in the same place, they are still moving a bit".

She encourages the students to move more and more and eventually they can no longer hold on to one another. She reminds them of the marbles at medium volume and asks the observers to comment on their motion. "They are moving separately but really still take up the same space".

A term actually used by the teacher – is this problematic?

Eventually the movement is too great and the 'pressure' from the students causes the tables to push away and the students spill out from their 'pen' across the floor.

The students move back to their seats and begin to work on their written tasks. They are to write up their observations from the speaker, noting the movement of the ball bearings at the three different volumes. Then they start to write a description of what happened to them when they were in the role-play.

An apparently purposeful linking/processing procedure. Was this the teacher's intention? Do the students reflect on the links?

The terms solids, liquids and gases are readily used now and their homework task is to attempt to describe melting, freezing, condensing and evaporating.

This classroom window is recreated from a teacher's account and so tends to follow the 'ideal response' line. It lacks any sense of the variety of comments and thoughts and questions that students might come up with in a classroom situation. As a result, any sense of the responsiveness of the teacher is also lost. This occurs at two levels. Within a lesson or an activity the decisions a teacher makes about what to say or do to help the students make sense of what is going on will differ in response to the students' words or actions, whilst at another level, we gain little sense of why the teacher decides to use this activity at all to help the students engage with this content. In other classroom windows the decisions that need illuminating might include: why a question is posed in a particular way; or, why highlighting something about *x* is important before presenting *y*; or, why the teacher decides to teach about a particular science idea at all.

Interestingly, including the dimensions of teacher thinking and decision making (and so bringing the account closer to questions about teaching the particular content) may well re-introduce 'dilemma' into classroom windows, meaning case methodology may sometimes be valuable in portraying some elements of PCK in action (for example, Ingvarson et al 1995; Kleinfeld, 1992). However, we believe it is fair to assert that the vignette and the callout boxes illustrate that there are some important features of portrayal that are crucial in offering insights into PCK. These include:

- classroom reality (including a diversity of students' responses)
- teacher's thinking (about the content AND the responses from the students)
- students' thinking (the links they are/not making and why)
- 'what it is about the content' that shapes the teaching and learning and why

Yet despite these features, we also believe that no matter how rich in these areas the portrayal of a 'classroom window' might be, alone a classroom window is likely to still be inadequate as a vehicle for portraying pedagogical content knowledge in a way that will be of profound use to teachers. In a similar way, this point is also important for educational researchers as recognising such complexity can also highlight the value of the knowledge of practice.

BEST COPY AVAILABLE

As our understanding of PCK has developed, we have realised that it is very difficult to offer a single example that is a neat concrete package, able to be analysed and dissected or used as a blueprint for practice by others (hence the lack of examples in the literature).

Science teachers, as noted earlier, have little opportunity, time, expectation or obvious reason to engage in discussions that help them to develop the tacit knowledge of their professional experience into explicit, articulable forms to share across the profession. Rather, they share activities, teaching procedures and clever insights into teaching and learning that have implicit purposes in practice. From these, other teachers can interpret the implied – but rarely stated – meanings, which underpin the practice. There is no existing culture of sharing teaching in other ways (although the development - described above in the method – of a collective methodology that cultivates a teacher discussion of this special knowledge of content by starting from a 'real' question about 'good teaching' may well be a step towards this).

However, instances of professional experience and pedagogy help to suggest the ways that particular concepts and content are grasped by particular science teachers and consequently shape the manner of their teaching. Thus, we have developed from the more general 'classroom window' (including the case form) what we have termed a PaP-eR (Pedagogical and Professional-experience Repertoire).

Portraying PCK: the development of PaP-eRs

Our conception and development of PaP-eRs as a form for portraying PCK hinges on two important issues:

- PaP-eRs are 'of' a particular content area - and are therefore 'attached' to that content.
- One PaP-eR ***cannot alone carry PCK*** – a diversity of PaP-eRs helps to shed light on the different aspects of PCK.

If a representation of PCK is to help teachers to recognise, articulate and develop their understanding of that content, then clearly it must be based on an understanding of what it **is** about the content that the teacher knows (and has come to understand) in order to purposefully shape the pedagogy and the associated approach to student learning.

We therefore propose a central representation of content (but not that this be viewed as static or as the only/best/correct representation) that sets out and discusses the aspects of PCK 'most attached to that content' (such as, for example, an overview of the main ideas; knowledge of alternative conceptions; insightful ways of testing for understanding; known points of confusion; effective sequencing; and, important approaches to the framing of ideas). This we illustrate with a 'notionally filled' version of Table 1, described above as part of our approaches with small groups of teachers. (This 'notionally filled' version is Table 2 below). It is crucial that we emphasise that this representation is what we have settled on at this stage as a methodology for accessing science teachers' understanding of the content. It is not

the representation that must be accepted and followed by all. It is a necessary but incomplete generalization resulting from work with teachers. It is being used to help codify information so that the links between the representation and the PaP-eRs attached to that representation are meaningful and in accord with the perceived understanding of the particular content; it helps to make the complexity accessible and manageable, and is neither complete nor absolute. Similarly, as a methodology, it is also important to stress that all of the cells in the table need not be 'filled in' and that the representation will vary in emphasis and understanding across different groups of science teachers.

Attached to this central representation are the PaP-eRs, with links to the aspects of this field that they 'bring to life' (see Table 2 and the two PaPe-Rs). Through our research we have come to see the value in putting this central representation together through the interaction of a group of teachers and researchers. As, and when, it is constructed, it projects various shadows and patterns onto the different classroom windows: these are the PaP-eRs that might be developed to show this 'mutual complexity' to others. Somewhat paradoxically, this approach limits what can be portrayed but at the same time also renders it accessible, and therefore useful to others.

Science teachers' understanding of the content, their particular views of teaching and learning within a context, and the subtleties of their practice in response to the learning (and other) demands of their students are all insights into their PCK but are not, of themselves, PCK. A PaP-eR must be 'of' a content area: it must allow us to look inside a teaching/learning situation where it is the content that shapes the pedagogy. The PaP-eR's embedded questions (or other links) should help to connect the 'practice' seen, with the explicit body of knowledge about the content central to the particular representation. That link should illuminate the decisions underpinning the teacher's actions that are intended to help the learners make sense of the content.

The PaP-eRs are about teaching ***that*** content in ***that*** context and help to illustrate aspects of PCK. The more specific a PaP-eR is to a particular classroom (as opposed to a more generic, "This is how I always teach States of Matter"), the more the PaP-eR illuminates the important links between teaching and learning - this is brought about by inclusion of specific student responses and the particular actions by the teacher in light of those responses.

Including a collection of PaP-eRs attached to different areas of the content might also highlight some of the different blends of elements that jointly contribute to an individual's (or group of science teachers') PCK. Therefore, as in Figure 1, the overlap, the interplay, and the relationship between PaP-eRs in a content area is important in viewing the complex nature of PCK without any one PaP-eR being regarded as the nature of PCK itself. To illustrate this we offer the following central representation (Table 2) and two PaP-eRs on States of Matter.

Table 2: Central Representation Table to Accompany PaP-eRs on Particle Theory.

TOPIC: **Particle Theory**
YEAR LEVEL: **7 - 9**

	IMPORTANT SCIENCE IDEAS / CONCEPTS						
What you intend the students to learn about this idea.	**A.** matter is made up of small bits (particles) **$#**	**B.** there is empty space between the particles	**C.** particles are moving and in a certain arrangement >> phase changes **#**	**D.** particles of different substances are different	**E.** different kinds of particles that, when joined, are different again ie. different 'smallest bits' **#**	**F.** conservation of matter: particles don't disappear or get created – they change	**G.** concept of a model to explain things we observe
Why it is important for students to know this.	Explaining the behaviour of everyday things (applies to whole topic) **#$**	Ability to compress things	Explains phase changes eg need to contain gases because of movement **#$**	explains behaviour of diff. substances	Explains why there are a limited number of elements, but many different kinds of compounds. Concepts of molecule & atom **#**	in any reaction involving matter must be able to account for all of the matter	concerned with ideas of nature of science but specifically particle theory is constructed rather than discovered
What else you know about this idea (that you don't intend students to know yet).	Subatomic structure Chemical reactions Ions (links to electricity) Generalisations about properties of materials (maybe) More complicated models Links to thermal properties of matter/diffusion				the bits themselves are different when combined (eg ions, change in subatomic arrangement)		
Difficulties/ limitations connected with teaching this idea.	Particles are too small to see. **#$**	big difference between macro (seen) and unseen eg. wood seems solid >> hard to picture empty space between particles.	macro properties are a result of micro arrangements. State implies separate and fixed while Phase gives idea of continuum. Difficult to imagine particles in a solid moving. **#**		Stds. can come to think molecules disassociate in boiling water **#**	bits are rearranged to create a different substance from existing bits (integrity of particles)	***CONTINUED OVER PAGE***

23

24

Knowledge about students' thinking which influences your teaching of this idea.	Nearly all stds. will use a continuous model (despite former teaching). #$	'space' hard to think about – most stds.. propose other 'stuff' between particles.	Stds. Have commonly encountered states of matter but not understood it in terms of particle movement. #	stds. tend to internalise a model from the text that shows circles all same size.	Stds. use terms molecule and atom without understanding concepts #	stds. believe that new stuff can appear	

Other factors that influence your teaching of this idea.	Maturity – stage of psych development, readiness to grapple with abstract ideas. Dealing with many different student conceptions at once. Knowledge of context.						
Teaching strategies **(and particular reasons for using these to engage with this idea).**	Probe eg draw air removed from flask (promotes std. thinking; uncovers individual views). Analogies eg sand (represents small bits making up solid whole). $	POE eg syringe (asks stds.. to predict outcome based on different models of matter). mixing activities eg meths and water / salt and water (outcome can be explained by empty space between bits). comparing models.	Translation activities eg. Role-play, modelling, drawing. #$ #$	mixing activities (can model explanation of water & meths mixing using balls of different sizes)	POE eg water boiling (creates need for different kinds of smallest bits). Modelling with specific materials (explore possible combinations in new things). #		
Specific ways of ascertaining students' understanding or confusion around this idea (include likely range of responses).	Explaining thinking and defending views. Making predictions about new situations.						

Nb: $ indicates link to PaP-eR 1: Seeing things differently.

# indicates link to PaP-eR 2: What is the smallest bit?

BEST COPY AVAILABLE

A PaP-eR of the Particle Model

Seeing things differently

Introduction

This PaP-eR illustrates how important the teacher's understanding of the content is in influencing how she approaches her teaching. In this PaP-eR, the teaching unfolds over a number of lessons but is based on the view that understanding how a model can help to explain everyday phenomena requires continual revisiting and reinforcement with students. The PaP-eR closes with an illustration of how inherent contradictions in teaching resources need to be recognised and addressed in order to minimise the level of 'interference' in learning specific concepts and how important that is in teaching about models.

Rhonda is a Chemistry major with a commitment to making science meaningful for her students. She enjoys teaching States of Matter and has developed a number of important 'frames' for approaching the content so that her students will better grasp the ideas rather than simply learn how to 'parrot' the appropriate 'science' responses in a test.

Rhonda's framing in the interview – the content (in Rhonda's voice)

At Year 7 level it really is only a very limited particle theory that I teach - I don't go into atomic structure in any serious way. I try to introduce the students to the idea that everything around them is not continuous but made up of small particles that fit together. I don't try to give any detail about how they fit together but I do talk with them about the particles being roughly spherical objects that are very, very, very, very, tiny.

I know that getting them to a particle model is not going to fully happen: they will revert to a continuous model when they are pushed. But it is important to start moving them some way along the path - to get them to consider that there may be another way of looking at the things around us. The ideas also need to be linked to what is happening during phase changes (melting, freezing etc.) and that link needs to be at the very small level rather than at the macroscopic level. So these two ideas influence how I approach the teaching.

It's important to continually remind yourself that particle theory at year 7 and 8 needs to be presented in helpful ways. I believe that maturity plays an important part in what you can actually grasp at a certain age. It's easy, as the teacher, to forget how conceptually difficult and conceptually abstract this topic is. It is an important topic to teach about though, because it's one of those building blocks of chemistry and it

helps you to build it in layers through science over the years rather than trying to do it all at once. It's conceptually meaty so I enjoy teaching it!

So what do I do? Well I suppose the first issue is helping the students to start thinking about what they're looking at differently. It's important to help them realise that although the things they are looking at appear to be made up of one thing – like a piece of pipe is made up of metal – you can break it down until it is made up of lots of small things combining together. A simple analogy is a jar of sand. From a distance it looks like one thing, but up close you can see the individual grains of sand.

From this, you can begin to explain the behaviour of everyday things in terms of movements of particles; this is a big shift in thinking for students. Again, you can play with this idea by getting something like a marshmallow and putting it in a gas jar and changing the pressure so the behaviour of the marshmallow is affected[6]. It helps to illustrate the point about small bits moving or acting differently in response to the conditions. The marshmallow is also good because it is an example of something they are familiar with and linking to their everyday experiences really matters - I've built up quite a few of these examples in my teaching over the years, it's good fun too.

The other idea to try and aim for is the idea of space, nothing, between the particles: it's really hard. One way of helping to address this is by using the demonstration of mixing water and methylated spirits. You add equal volumes of them together, if each liquid is one big block of water or metho, then the volume should be double, but it isn't so how come? That helps to make the point about the spaces so that in this case things can fit between the spaces.

So overall I suppose really I'm only concentrating on three things:

1. Things are made up of tiny little bits
2. There is space between the tiny little bits
3. You can use the model to explain phase changes etc.

But I don't mean to make it sound as simple as that because really what I do is respond to what's happening in the class. Last year I went 'down the density path' even though I wasn't intending to. But, because it was their questions that took us there, I let it go on and followed it for longer.

The point really is that the use of the particle model is a *way of thinking* and it's something that the students have to be reminded of so that they think about things from that perspective, rather than reverting to their continuous model perspective.

[6] The behaviour is described later.

Rhonda's framing in the classroom – "imagine"

The unit starts with Rhonda asking the students to imagine that they have been shrunk down so that they are very tiny and then they fall into a droplet of water on the lab bench. They have to imagine what the droplet looks like from the inside, and then they write a short adventure story and draw a picture of what they can see. The students' pictures show a range of responses, a handful contain dots but most of these are explained as being "the dirt and stuff in the water".

Through a number of activities and discussions over several lessons Rhonda introduces the class to the content ideas that she outlined in the interview.

Then Rhonda gets all of the students to make a pair of cardboard glasses. They decorate these in whatever way they wish. She encourages them to use their imagination in designing their "magic glasses". Putting the glasses on is a cue for them to think in terms of particles.

> "One of the problems I find is that they easily revert back to a continuous model, so putting them in a situation where they wear the glasses and look at something helps them to better understand how the model works to explain what they are seeing. You can get them to put them on at different times throughout the unit and it helps them make the transition to particle model thinking."

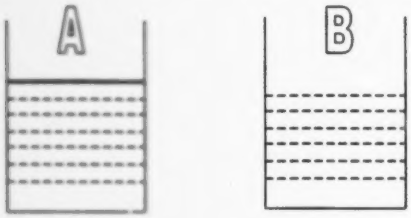
In one lesson Rhonda fries onions on the front bench in the laboratory. The students call out from their seats when they start to smell the onions. They track the progress of the smell towards the back of the lab. Rhonda asks them to put on their glasses and look around the room. Can they explain the smell through particle theory?

She asks them to think about when they mixed the methylated spirits and water together. With their glasses on they need to describe what is happening as the two liquids combine.

Rhonda shows the class a marshmallow inside a gas jar. By varying the air pressure in the jar she causes the marshmallow to swell up and then eventually collapse. She asks the students to think about the air inside the marshmallow. If they could 'see' it through their glasses how could they explain what was happening to the marshmallow?

The class revisits their shrinking adventure in the drop of water. Rhonda asks them to think carefully and draw what the inside of a drop of water would be like with the 'magic glasses' on.

Rhonda shows the interviewers diagrams representing water from a couple of textbooks.



"If you look at the pictures in books they often show liquid as particles but the liquid is capped by a continuous line (diagram A), which inadvertently undermines what we're trying to get students to understand by these representations of a particulate model. The students end up thinking that the water is the clear stuff and the particles are just dots in the water."

Rhonda decides that this year she will ask the class to look at a beaker of water through their glasses and to decide which of the two diagrams best represents water and why they think so.

"If the students are wearing their glasses when they look at a beaker of water they should see diagram B rather than diagram A. And be able to explain why they do!"

A PaP-eR on Particle Theory

What is the smallest bit?

Introduction

This PaP-eR has been constructed as a result of two teachers (MB and PM) reviewing their learning during their team teaching whereby their approaches and ideas about the classes they taught and shared were documented through a journal that they maintained as an 'added' form of communication. The journal entries in the PaP-eR are highlighted through changes in formatting.

As this PaP-eR 'opens' the class have already moved through several activities and discussions that have helped them to consider the ideas that matter is made up of tiny, tiny bits and that these bits have nothing between them. They have started to consider that these particles (the smallest bits possible) are moving and hence have a particular arrangement, and that these factors help explain what phase a substance will assume.

These teachers have, in essence, covered the content ideas that Rhonda described. In this account they attempt to create a need for different kinds of particles, by asking students to explain (using different media) what happens as water boils. This teaching sequence also revisits and reinforces the content ideas already covered.

MB – teaching journal entry

The need for molecules.

Read this POE. It's designed to help students understand the structure of water and seems perfect for differentiating between particles generally, and atoms and molecules.

The teacher asks the class of year 9 students if they know what the chemical shorthand for water is. A number call out, they have all heard it before, and the class quickly settles on H_2O. What does that mean? Easily the class agrees that it means water is made of H and O and that there is twice as much H as O.

The teacher then asks them to draw a "super-magnified" picture of how a beaker of water might look if we could see how the H and O are arranged in it. Students think and quietly draw their own pictures.

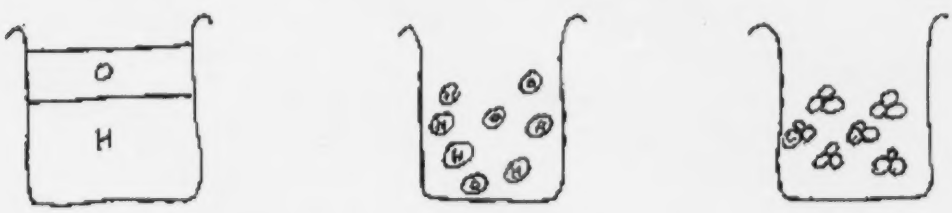
The teacher asks them to look at a beaker of water boiling at the front of the class, and to imagine the steam above the beaker. Students each draw a "super-magnifier" representation of what this would look like. The teacher walks around and asks several students if they would like to put their diagrams on the board so that there are a range of ideas shown for both liquid and gas.

PM – teaching journal entry

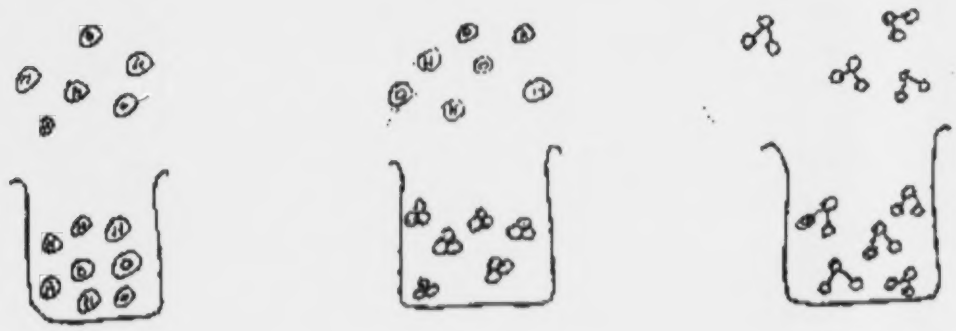
9G:It seems this idea of 'the smallest bit' is really the important idea to come to, and it would have been confusing talking about atoms to start with (especially as everyone knows that water is H_2O and has constructed some vague idea of what that means, even if just that it's made of hydrogen and oxygen).

It's amazing the constructions of what water being H_2O and so made of two parts hydrogen to one part oxygen means to them – this is the best lesson I've ever had about the variety of interpretations that can fit one piece of information!

I'm always a little bit nervous asking them to bare their ideas on the board, but lots of people were very willing. Lots of thanks and praise of course!



Picture 1: (examples of individual student's pictures of water in a beaker drawn on the board)



Picture 2: (examples of individual student's pictures of boiling water in a beaker drawn on the board)

People were pretty strong on the idea of ratio - it was important to them that it was two parts hydrogen to one part oxygen (is this just the power of the annotation - because the formula says so??). I'm still amazed at the first one - after all the work we (they!) have done with particles..... Several students commented on this: "it can't be that - it has to be made of particles". Picture 1(and to some extent picture 2) was challenged by asking what would happen if we tipped some of the water out of the beaker. There was some debate as to whether it could "even itself up" but it generally offended their notion of the 2:1 ratio. So we were left with hydrogen and oxygen either separate or together.
Of course all the "separates" in liquid were separate in gas (what would we do if they weren't!). Of the others only Carolyn and Polly kept the molecules together in the gas, the rest had them separating into hydrogen and oxygen.
In the end most of the class were happy with picture 3 as the best representation of water, so we moved on to work out how we could decide which was the best picture of the steam.

The teacher asks the class how they could find out whether boiling water really does separate into hydrogen and oxygen as it boils. When students suggest somehow testing to see if those gases are there, the teacher is ready to produce, and then demonstrate the presence of, hydrogen in a test-tube. She asks the class what it will mean (in terms of choosing the best picture) if they do find hydrogen above boiling water, and what it will mean if they don't.

MB - teaching journal entry
9R:Demo'd hydrogen test - they loved it (have to be careful that the 'bang' isn't the only thing they remember). Sarah T tested the water vapour for hydrogen (she was pretty nervous). Nothing happened (of course).
Next point they said that the H stays behind and oxygen is given off.(!)
Kylie G: maybe it separates into the H and O gases then recombines again and that's why you feel the water droplets on your hand if you put your hand over it.

Loughran, Gunstone, Berry, Milroy and Mulhall. A paper presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, April, 2000.

Steph: but when we see the pics in the book it says solids 'break up' into liquids, so then the liquid also 'breaks up' into a gas, therefore H_2O breaks up into H + O.
Bron: yeah, and we did the role-play about ice melting and water boiling we all had to break apart and run around the room then (she looked pretty smug). [A problem I'd never thought of before but which seems pretty obvious now it's pointed out.]
There wasn't time to work through all of this but what I LOVE is that they are fighting for those models, and coming up with ideas to defend them as hard as they can. LOTS of thinking....
You've got 9R next - you need to: 1.demo O_2 test and test boiling water >>> which is most likely model?
2. acknowledge Kylie G's observation and deal with it (no H or O found by testing)
3. introduce term molecule as the smallest bit of water and link that back to the role-play (ie acknowledge Bron's point and help them understand that the people were molecules / smallest bits of water)

MB demonstrates a similar test for oxygen and a student applies it to the boiling water. Via a great deal of class discussion consensus is reached that picture 3 is the most suitable one to represent water as liquid and as steam.

Students draw diagrams again in their books, and write down how they know that the hydrogen and oxygen stay together as water boils. Their next writing task asks them to apply the new terms atom and molecule in describing water (and some other substances).

--------§--------

The classroom is set up in the following way for the next lesson.

Beaker of water boiling out the front. Students, with a partner, are to: Draw big pictures that show what happens as water boils. Be ready to demonstrate their understanding to the teacher using some pieces of duplo.

PM - teaching journal entry
9G: The girls worked in pairs with textas on butcher's paper. They started off working on their explanations on the butcher's paper but eventually everyone had their duplo going to help them work out what the pictures actually should be. I'm sure it helps their thinking to be able to manipulate a model <u>while</u> they are trying to put snapshots of it down on paper. I'm sure that's a big problem with lots of the diagrams they get to see - it's hard to think about what's happened for one diagram to move on to the next.

The best bit was that working through the boiling water scenario with particular pairs of stds. (Tammie and Nat were struggling) led to me asking them to use the duplo to show the smallest bit of water they could possibly get. Then asking which of the terms (atom,

molecule, compound, element) we could use to describe it. It was REALLY POWERFUL for several stds.. "Is this still water?" or "What have I got now?" when breaking up the molecule. "Show me an atom of water" "... a molecule of an element" "...an atom of a compound" "... the smallest bit of an element" etc. It was easy to see which bits particular stds. were having trouble with, and to work through it with them then and there.

Overview

We do not envisage that PaP-eRs should have a particular format or style. A PaP-eR should be an engaging portrayal of the elements of PCK that are being illustrated for the reader. Therefore, PaP-eRs should have a variety of formats (eg. an interview, observer's voice, journals, window into a lesson, students' voice and actions, an annotated teaching resource, and so on) so that their portrayal allows the reader to identify with the situation and, as a result of the particular framing of the pedagogy, content and context, to draw meaning from it.

In concert with the PaP-eRs, the central representation (see Table 2) must be conceptualised (with a particular group of students' in mind) as a necessary construction to codify and categorise the knowledge and content under consideration so that it might be manageable and useful for others. Well-constructed PaP-eRs ***should*** then bring this central representation to life and shed new light on the complex nature of PCK both for teachers and educational researchers. This we see as one way of helping to create opportunities to better understand, and hence value, the specialist knowledge and skills of teachers and to make the tacit explicit for all audiences.

We realise that the use of PaP-eRs as a representation of elements of PCK has moved a considerable distance from case methodology as it is generally used. However, our proposed representation through PaP-eRs still contains many of the qualities that first inspired this investigation so that representation of PCK might indeed be possible. We contend that PaP-eRs then need to:

- capture the rich detail of classrooms so that they 'ring true' with teachers and engage them in thinking through a 'real situation'
- illustrate some of the central content representation, and/or may be the 'way in' ie reading a PaP-eR and grappling with the questions it raises may be the way a reader comes to consider certain aspects of the content in the first place; or comes to reconceptualise and extend their understanding of the content
- illuminate dimensions of teacher thought in concert with classroom action. Particularly so in relation to the thoughts and actions that combine in teaching ***particular*** content to particular students so that students' learning is enhanced.
- act as stimuli for reader thought and discussion and explicitly link to the central representation of the content.

Conclusion

In coming to better value teachers' knowledge and practice, there is a need to be able to articulate and document what it is that teachers know and are able to do and this is central in coming to understand science teachers' pedagogical content knowledge. Malcolm (1999) noted that in deconstructing one's teaching it begins to make the tacit explicit for others. In teaching, this is not a common approach to understanding practice - yet it must surely be an important element of a profession. Although Roth (1998) argues that the subtleties of quality teaching may defy analysis, we believe that there is a need to work to illuminate practice so that it can be viewed, analysed and understood by others.

Through this project our research team has examined Pedagogical Content Knowledge in such a way as to come to understand that it is ***not*** a single entity that is available and easily accessible in science teachers' practice. Our view of PCK is that much of what PCK may be is tacit in a science teachers' practice and that the ability to recognise and document it is influenced by the researchers' understanding of what they believe they are looking for.

The literature has demonstrated that PCK has certainly been well accepted by the academic community as a useful construct but convincing concrete examples of PCK are difficult to find. Our development of the PaP-eR as a way of documenting elements of PCK is one way of attempting to begin to portray PCK to others. As our project continues, we hope to develop a substantial collection of PaP-eRs focussing on particular content areas (eg. electricity, circulatory system, forces, the planets etc.) that combined will better illustrate the nature of PCK and begin to offer ways of sharing this within the profession.

References

Baird, J. & Northfield, J. (eds.) (1992). *Learning from the PEEL experience*. Melbourne: Monash University.

Berliner, D. (1988). Implications of studies of expertise in pedagogy for teacher education and evaluation. In Education Testing Service (Ed.), New directions for teacher assessment. *Proceedings of the 1988 ETS Invitational conference*. Princeton, NJ: Educational Testing Service.

Gess-Newsome, J. (1999). Pedagogical content knowledge: An introduction and orientation. In J. Gess-Newsome & N.G. Lederman (eds.), *Examining pedagogical content knowledge*. Dordrecht, Netherlands: Kluwer.

Grimmett, P. & MacKinnon, A.M. (1992). Craft knowledge and the education of teachers. In G. Grant (ed.), *Review of research in education, 18*, 385 – 456.

Hart, C., Mulhall, P., Berry, A., Loughran, J.J. and Gunstone, R.F. (In Press). What is the purpose of this Prac? or Can students learn anything from Prac Work? *Journal of Research in Science Teaching*.

Ingvarson, L.C., Livingston, J., Loughran, J.J., and Haslam, F. (1995). *Teaching Science: Getting Down to Cases*. A Monash University and Science Teachers' Association of Victoria project for the Department of Employment, Education and Training. Melbourne: Monash University.

Kadar, P. (1988). *Triggers for Reflection*. Unpublished Masters Thesis, Faculty of Education, Monash University.

Kleinfeld, J. (1992). Can Cases Carry Pedagogical Content Knowledge? Yes, But We've Got Signs of a "Matthew Effect." ERIC Document, ED344887.

Malcolm, C. (1999). Thoughts from South Africa. *Lab Talk, 43* (5), 48 – 50.

Mitchell, I.J. and Mitchell, J. (1997). *Stories of Reflective Teaching: A book of PEEL Cases*. Melbourne: PEEL Publishing

Roth, W-M. (1998). Teaching and Learning as Everyday Activity, in Fraser, B.J. and Tobin, K.G. (Eds.) *International Handbook of Science Education*, Dordrecht: Kluwer Press.

Schön, D.A. (1987). *Educating the Reflective Practitioner: Toward a New Design for Teaching and Learning in the Professions*. San Francisco: Jossey-Bass.

Schön, D.A. (1983). *The reflective practitioner: How professionals think in action*. New York: Basic Books.

Shulman, J.H. (1992). *Case Methods in Teacher Education*. New York: Teachers College Press.

Shulman, L.S. (1986). Those Who Understand: Knowledge Growth in Teaching. *Educational Researcher, 15* (2), 4 - 14.

Shulman, L.S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*, 1 - 22.

Veal, W.R. & MaKinster, J.G (n.d.) *Pedagogical content knowledge taxonomies*. Published electronically at http://unr.edu/homepage/crowther/ejse/vealmak.html

White, R.T. (1988). *Learning Science*. London: Blackwell.

[1] The research reported in this paper was supported by an Australian Research Council Large Grant (Loughran and Gunstone, 1999).